ARMY RESEARCH LABORATORY

Firing Data and Result From XM815/X-Rod Fin Slug Test

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Army is developing a tank main gun cartridge referred to as X-Rod. The X-Rod munition combines a kinetic energy projectile with a rocket motor booster and on-board guidance system. This ammunition is designed to provide a high probability of kill out to extended ranges. One portion of this program is the development of a fin system to provide the projectile with the required aerodynamic stability. This system must be packaged within the allotted spatial constraints, dictated by the current 120-mm cartridge configuration, and the geometric requirements of the remaining cartridge components. A "forward flip" deployment scheme has been selected to accomplish this goal. This concept includes eight rectangular fins that are attached to the projectile body via a single pivot pin. In the stowed position, the fins trail behind the projectile body. During in-bore travel, the fins remain in this stowed position until muzzle exit, when the blast acts to rotate the fins outward to the erected position. Several fin configurations were test fired to observe fin deployment characteristics. One of these arrangements included the addition of wedges to the fin tips to assist in fin deployment. The results revealed that none of the configurations tested were able to consistently rotate the fins a full 90°.

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1. INTRODUCTION

X-Rod is a tank ammunition development program that incorporates the use of a rocket motor and guidance system into a kinetic energy projectile. One portion of this effort is the development of a fin system to provide the required aerodynamic stability. This system must be packaged within the allotted spatial constraints, dictated by the current 120-mm cartridge configuration, and the geometric requirements of the remaining cartridge components. A "forward flip" deployment scheme has been selected to accomplish this goal. This concept includes eight rectangular fins that are attached to the projectile body via a single pivot pin. In the stowed position, this pivot point is located at the forward most portion of the fin with the remainder of the fin trailing behind the projectile body, as illustrated in Figure 1. During in-bore travel, the fins are designed to remain in the stowed position. Upon muzzle exit, the blast acts to rotate the fins outward to the desired position. Once a full 90° of rotation is achieved, the fins are locked in place by a spring and pin mechanism and remain deployed for the duration of the flight.

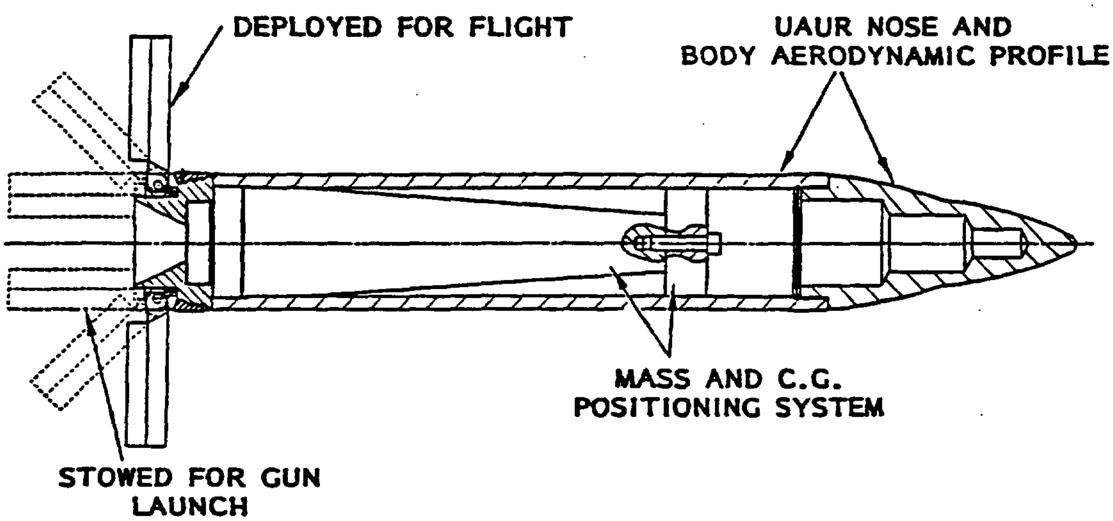


Figure 1. Schematic of forward flip fin design on X-Rod slug.

2. BACKGROUND

A previous tank projectile design, the 105-mm XM815 HEAT-T, also employed a forward flip technique for fin deployment. Developmental testing of the XM815 projectile revealed severe fin bending, immediately following launch, which contributed to excessive projectile jump. In some cases, plastic deformation of fins was evidenced (Bundy and Schmidt 1985). It had been concluded that this fin bending was the result of muzzle blast loading on the fins, which presented surfaces asymmetric to the muzzle flow. Although the XM815 was launched from a rifled gun tube, it did possess a slip band obturator to reduce the launch spin. However, the residual spin was ample to produce fin twist during in-bore travel. Upon muzzle exit, this slight twist, in combination with initial rates, presented ample area for the muzzle blast to act upon. Once a fin began to deflect, the amount of asymmetric area presented to the flow would increase, exasperating the effect until the fins exited the high-pressure area of muzzle flow. It was thought that by eliminating the rifled tube effects, the XM815 fins could survive a launch with minimal bending. However, this would alter the deployment forces by eliminating the centrifugal component. Therefore, the muzzle blast would be the only force contributing to fin rotation. Efforts were initiated to model this process in an attempt to predict fin deployment; however, due to the complexity of characterizing the gas flow around the fins, these efforts produced mixed results (Vogel and Crickenberger 1995). Due to various unknowns, regarding fin response within the muzzle blast, a firing program was deemed necessary.

The U.S. Army Research Laboratory (ARL), formerly the U.S. Army Ballistic Research Laboratory, had been involved with the XM815 program during the early 1980s and was in possession of excess hardware, including inert projectiles. These were offered as surrogate launch vehicles for a fin deployment test. In addition, a smoothbore 105-mm gun tube was made available. Due to the similarities between the XM815 and X-Rod fin systems, it was decided that the excess XM815 hardware, with minor modifications, could provide the necessary information at a significantly reduced cost.

Using a 105-mm gun system, as opposed to 120 mm, required the comparison of several interior ballistic (IB) parameters. A close match of both velocity and muzzle pressure, at shot exit, was considered the most critical for evaluation of fin deployment. The selection of a suitable propellant and charge mass were determined with the use of an IB code with attention to provide launch characteristics similar to the 120 mm (Robbins 1994). The results of these computations are included in Table 1.

Table 1. Interior Ballistic Computations

Gun System	Max Breech Pressure (MPa)	Max Acceleration (g's)	Muzzle Velocity (m/s)	Muzzle Pressure (MPa)
120-mm X-Rod	389.6	19,230	832.3	54.6
105-mm XM815	265.7	14,210	842.8	51.3

This data shows that the fins would be subjected to a similar launch environment from either gun system. The only parameter that did not lend itself to simple scaling was the blow-down history. Since the 120-mm tube contains more volume, it will contain more energy and exhaust over a slightly longer time. However, since the majority of blast impulse is delivered to the fins over the first few milliseconds, this was not considered a significant difference.

3. TEST SETUP

The experimental setup used for these test firings was located at the ARL Transonic Range Facility. The gun system consisted of an M68 105-mm smoothbore tube mounted in an artillery sleigh recoil system. Directly downrange of the muzzle were a series of four orthogonal x-ray stations. A pressure transducer was positioned alongside the gun muzzle and used as a triggering device. As the projectile obturator uncorks, the blast wave impinges on the transducer. The resulting signal is then used as the reference time to initiate the x-ray delay timers. This triggering method has been refined over the years and has proven quite successful. In addition, a series of smear cameras were positioned along the flight path to provide a photographic record of fin condition and deployment orientation. Furthermore, a high-speed underline camera was used to observe in-bore obturation and the initial portion of projectile flight. Lastly, several yaw cards provided a record of fin rotation and served as a redundancy feature in the event of trigger failure. Table 2 contains a complete list of instrumentation and setup details.

4. TEST FIRINGS

The projectile configurations were chosen to provide data on both the original XM815 design, launched with zero spin, and surrogate X-Rod designs. Therefore, two thicknesses of aluminum XM815 fins as well as the titanium X-Rod fins were evaluated. In addition to the materials, a major design

Table 2. Test Instrumentation

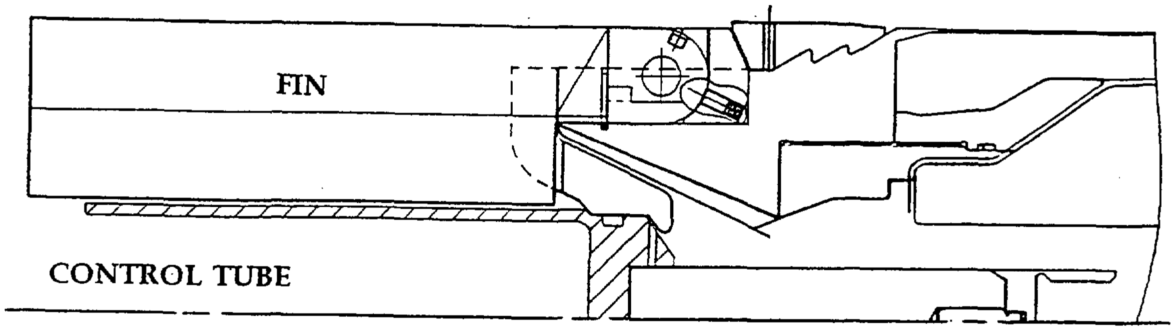
Instrumentation	Description
Two M11 Crusher Gages in base of cartridge case	Peak Chamber Pressure
Downbore Camera (Mirror Image)	Color: Projectile SNs 001, 002, 003, 004, 006 Black and White: SNs 005, 007
Smear Cameras	Locations and type of film: 2.74 m; B&W for all rounds 6.81 m, 13.59 m, 23.65 m, 32.31 m, 47.29 m; Color for SNs 001, 002, 003, 004, 006 B&W for SNs 005, 007
X-Rays[a]	Locations: 0.24 m, 1.05 m, 1.79 m, 4.33 m
Yaw Cards	Locations: 41.86 m, 210.31 m
Target	213.36 m
Weibel Radar	Velocity
Meteorological Data[b]	Windspeed (m/s) Relative Humidity (%) Air Temperature (F) Barometric Pressure (in)

[a] A pressure probe located next to the muzzle was used to provide a time zero for projectile exit.

[b] Meteorological data was recorded twice per day—once just before the first shot in the morning and again before the first shot in the afternoon.

difference existed between the fin types. The XM815 fins require only 37° of rotation to lock into the fully deployed position, while the X-Rod fins were designed to require a full 90° of rotation before lockup, as shown in Figure 2.

A titanium alloy was selected as the X-Rod fin material due to the combination of aerodynamic heating and high structural loads that a tactical fin could potentially experience during flight and maneuver. In order to minimize drag, the X-Rod fin design was much thinner than either of the XM815 fins. To provide in-bore protection for the titanium, a two-part coating was applied using a plasma flame spray. This coating consisted of a bond layer followed by a yttria-stabilized zirconia top layer. The two X-Rod configured rounds also included a surrogate control tube, with fin cradle struts, as depicted in Figure 3. This device was designed to simulate the discarding control tube mechanism of a tactical projectile. For the purpose of this test phase, the tube mechanism was permanently attached to the projectile base.



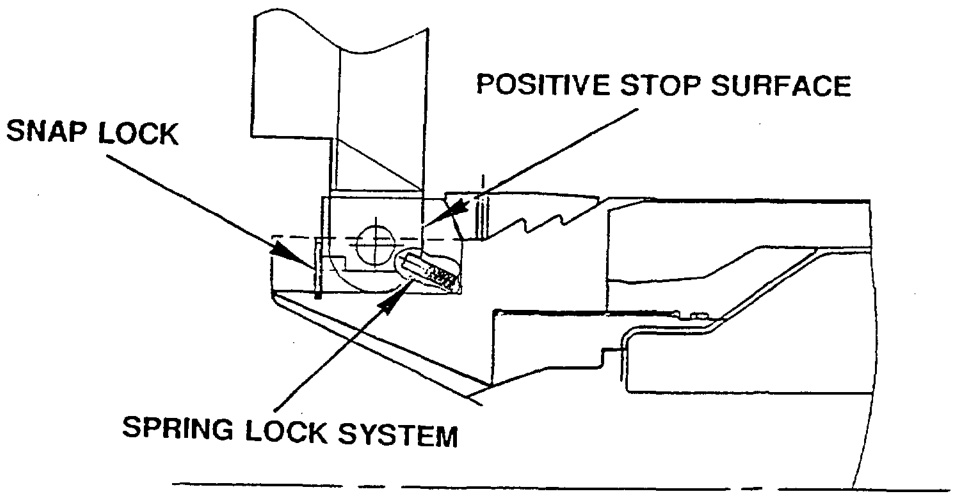


Figure 2. Details of fin deployment system while in-bore (top) and in-flight (bottom).

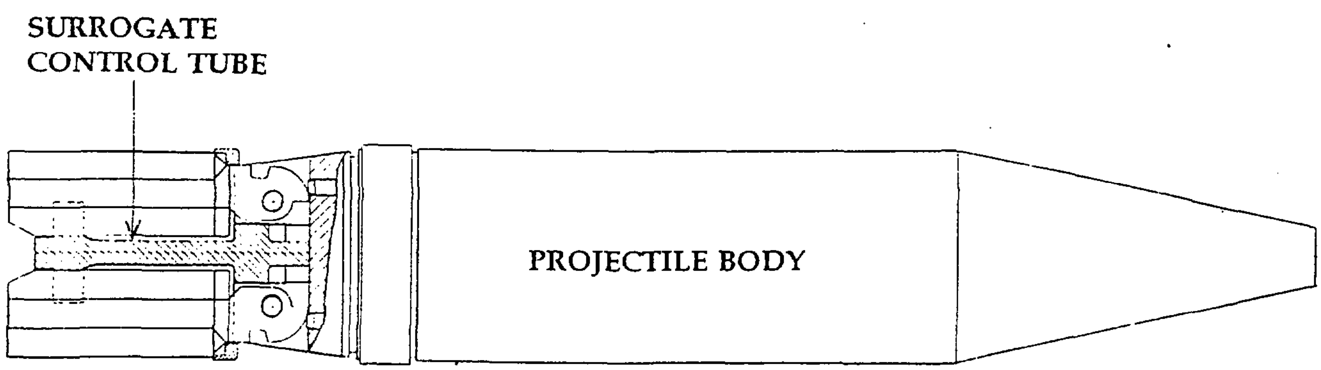


Figure 3. Illustration of X-Rod surrogate projectile.

The test series also included several other projectile configurations; each contained a unique feature worthy of evaluation. These included one round with three X-Rod fins and three XM815 fins in an alternating pattern. The XM815 fins were reduced in length to match the X-Rod fins. Another contained only XM815 fins pared down to X-Rod fin length. A final configuration consisted of XM815 fins of X-Rod length with a wedge tab attached to the tip of each fin. These clips were an attempt to simulate a discarding clip design proposed by Alliant ABL. Table 3 summarizes the projectile configurations.

Table 3. Test Series Description

Projectile Serial No.	Round Number	Projectile Description
001	33165	Standard XM815; thin Al fins, epoxy coated
002	33166	Standard XM815; thin Al fins, epoxy coated
003	33167	Hybrid; three X-Rod fins, Ti with ceramic coating, three XM815 fins, thin Al, epoxy coated, cut to X-Rod length
004	33168	Standard XM815; thin Al fins, epoxy coated, cut to X-Rod length
005	33171	Standard XM815; thick Al fins, uncoated, cut to X-Rod length with Al clips on fin tips
006	33169	X-Rod configuration; Ti fins with ceramic coating, control tube
007	33170	X-Rod configuration; Ti fins with ceramic coating, control tube

5. TEST OBJECTIVES

The primary test objectives, as listed in the referenced test plan, included:

(1) Comparison of the effects of rifling vs. smoothbore tubes on the launch survivability of forward flip fins.

(2) Evaluation of higher strength fin material (titanium vs. aluminum) as a means of increasing launch survivability.

(3) Examination of the feasibility of gun blast as the sole means of deploying forward flip fins.

(4) Evaluation of a passive mechanical device (i.e., tabs) to assist in fin deployment.

6. TEST PLAN DEVIATIONS

The following deviations were made from the test plan:

(1) The fifth round fired was SN 006 rather than SN 005 as called out by the test plan. This deviation was made because the fifth round of the program was to be the last round for that week. It was decided that an X-Rod configured round should take priority to allow review of the data before the next firing day.

(2) Test round SN 003 called for aluminum tabs to be welded onto the fin tips to aid in fin opening. However, the first attempt at welding produced distortion in the fin. Therefore, the tabs were attached using a No. 10-32 capscrew, several roll pins, and silver solder.

(3) The propelling charge used for all test rounds consisted of 3.7 kg of M30, 7-perf cylindrical propellant, Lot No. RAD81J-070121. The charge mass was revised upwards from an initial computed estimate of 3.5 kg as the result of two charge development firings using the same projectiles. The first of those firings, loaded with 2.75 kg of propellant, resulted in a muzzle velocity of 675 m/s and a maximum breech pressure of 20.8 ksi. The second, loaded with 3.5 kg of propellant, launched the projectile at 806 m/s, with a maximum breech pressure of 34.9 ksi. After slight modifications to the propellant burn characteristics, the IB code indicated that 3.7 kg would achieve the required 840 m/s muzzle velocity.

7. DATA AND OBSERVATIONS

Individual round data and observations are included in Appendix A.

The opening angles of the fin set parallel to the x-ray plane was measured directly from the x-ray film. These angles and the x-ray flash times are contained in Appendix B. The data presented in this appendix does not account for the out-of-plane roll of the projectile and distortion produced by x-ray magnification.

These factors can affect the measured vs. actual opening angles of the fins and could result in a measured angle that was underestimated by as much as 5° (Maurizi 1995).

Plots of velocity vs. distance for each round, obtained from Weibel radar, are included in Appendix C.

8. SUMMARY

8.1 XM815 Projectiles. The data indicates that the aluminum XM815 fins, both thin and thick versions, survive the in-bore and muzzle exit loads. The thin, full-length aluminum fins of rounds 33165 and 33166 exhibited noticeable deflections while traversing the reverse flow region (see Figure 4). However, this is in contrast to the more severe fin deflections encountered during XM815 developmental testing (Bundy and Schmidt 1985). This difference in severity of fin deflection verifies that the projectile spin is responsible for producing deflections in-bore that carry through to the muzzle, at least for the aluminum fins. These initial fin deflections result in asymmetric surfaces upon which the muzzle flow impinges. The gas dynamic loads then amplify the initial deflections, as observed during earlier XM815 testing. As for the thin aluminum fins shortened to X-Rod length, rounds 33167 and 33168, the deflections were significantly reduced to the point of being difficult to observe on the x-ray film. The thick aluminum fins, with deployment assist wedges (round 33171), showed no fin deflection, as evidenced in Figures 5 and 6.

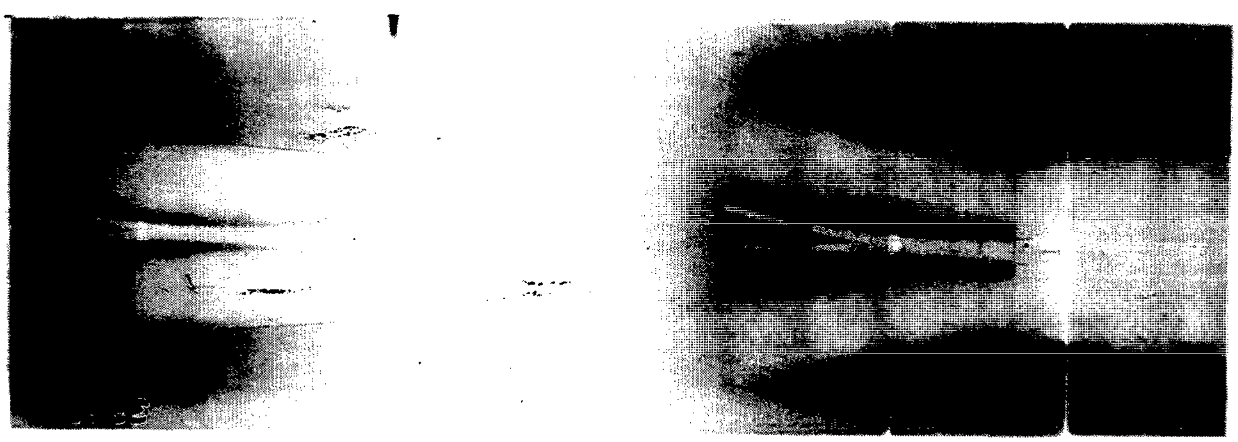


Figure 4. Round No. 33166, 0.24-m x-ray (left) and 1.05-m x-ray (right).

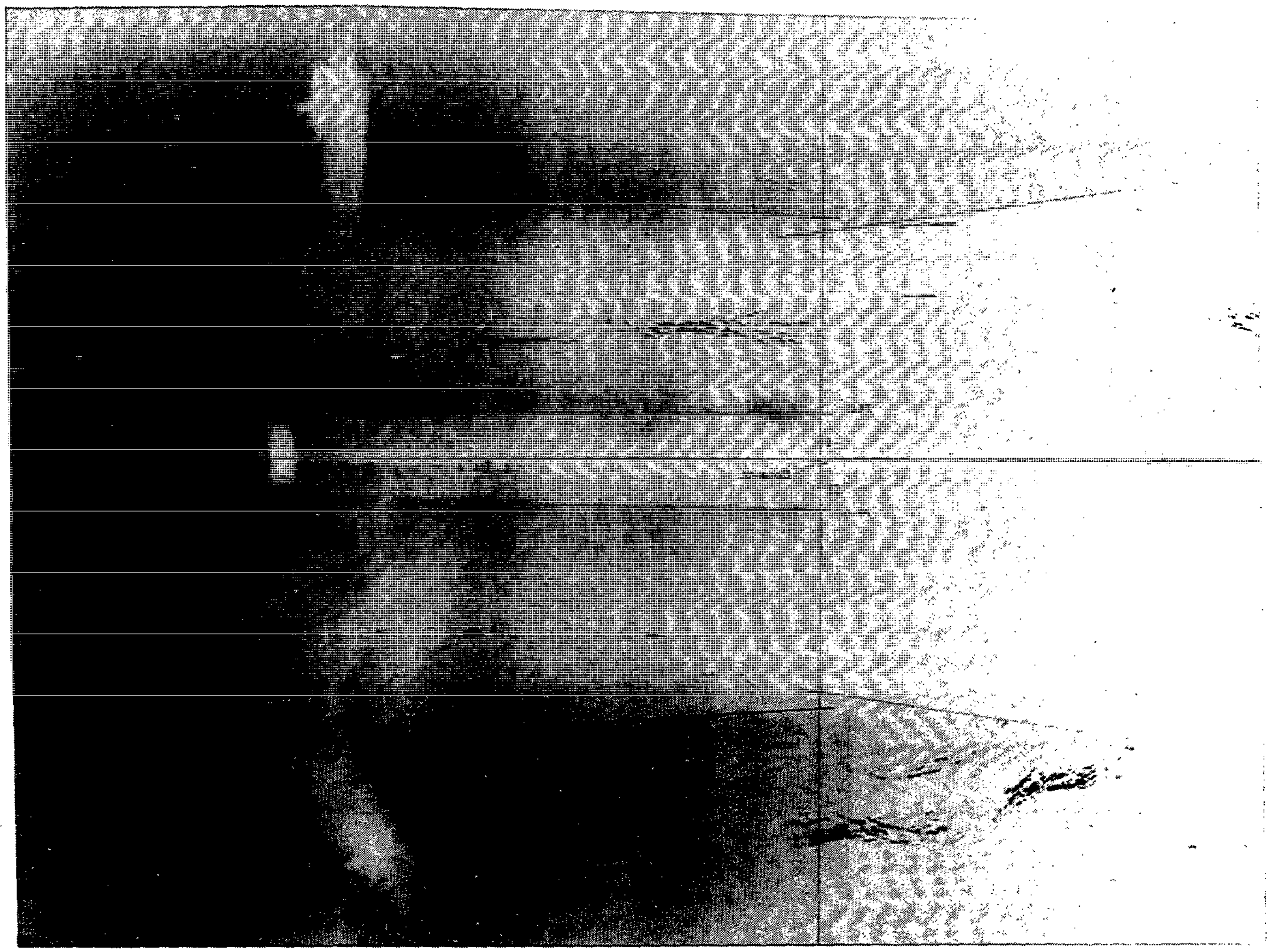


Figure 5. Round No. 33171, 0.24-m x-ray (short, thick Al fins with tabs).

Of the aluminum fin sets fired, the results indicate that the thin XM815 fins fully deployed 58% of the time (7 out of 12), while the thin XM815 fins cut to X-Rod length achieved full deployment 89% of the time (8 out of 9), refer to Figures 7 and 8. In addition, the shortened XM815 fins with deployment assist wedges fully opened 100% of the time (6 out of 6) (see Figures 9 and 10). The results demonstrate that the blast loading on the fin surfaces alone was insufficient for the fins to repeatedly achieve full deployment, even to the 37° position. However, the projectile with assist wedges (round 33171) successfully deployed all fins. Even though the assist wedges were ripped from the fins soon after muzzle exit (refer to Figure 5) the additional impulse was sufficient to increase the opening angles (see Appendix B) and allow full deployment.

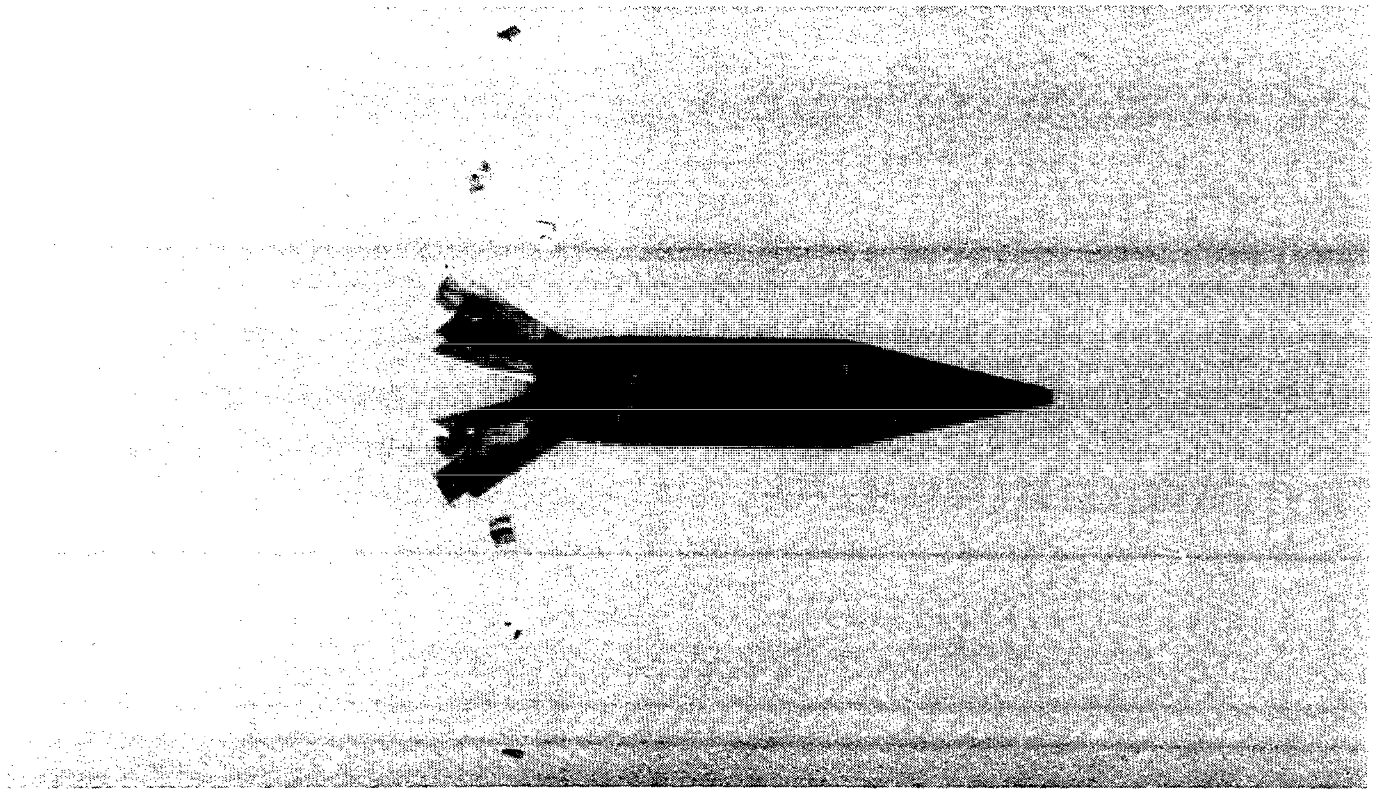


Figure 6. Round No. 33171, 2.74-m smear camera (short, thick Al fins with tabs).

8.2 X-Rod Surrogates. Although all the X-Rod fins survived the launch event intact, a number of fins experienced significant deflection while traversing the muzzle flow region, as seen in Figures 11, 12, and 13. In addition, none of the X-Rod fins reached full deployment (0 out of 15) on either of the two X-Rod configured rounds or the one hybrid round (refer to Figures 14 and 15). In fact, the largest deployment angle measured on any X-Rod fin was only 22.5°. The control tube, with integral fin cradle struts, seemed to provide no lateral support to the fins while traversing the reverse flow region. In addition, the ceramic fin coating did not appear to survive the gun launch intact. A large number of particles were observed trailing the fins in both the x-rays and smears. These are presumed to be chips of the brittle coating that was cracked during the large fin deflections. Also, it appeared as though some burning took place where the struts of the control tube cradle retained the fins. This is visible in some of the downrange smears, as evidenced in Figure 16. Possible explanations include either burning propellant, which was dragged along by the control tube struts, or pyrophoric burning of the unprotected titanium parts.

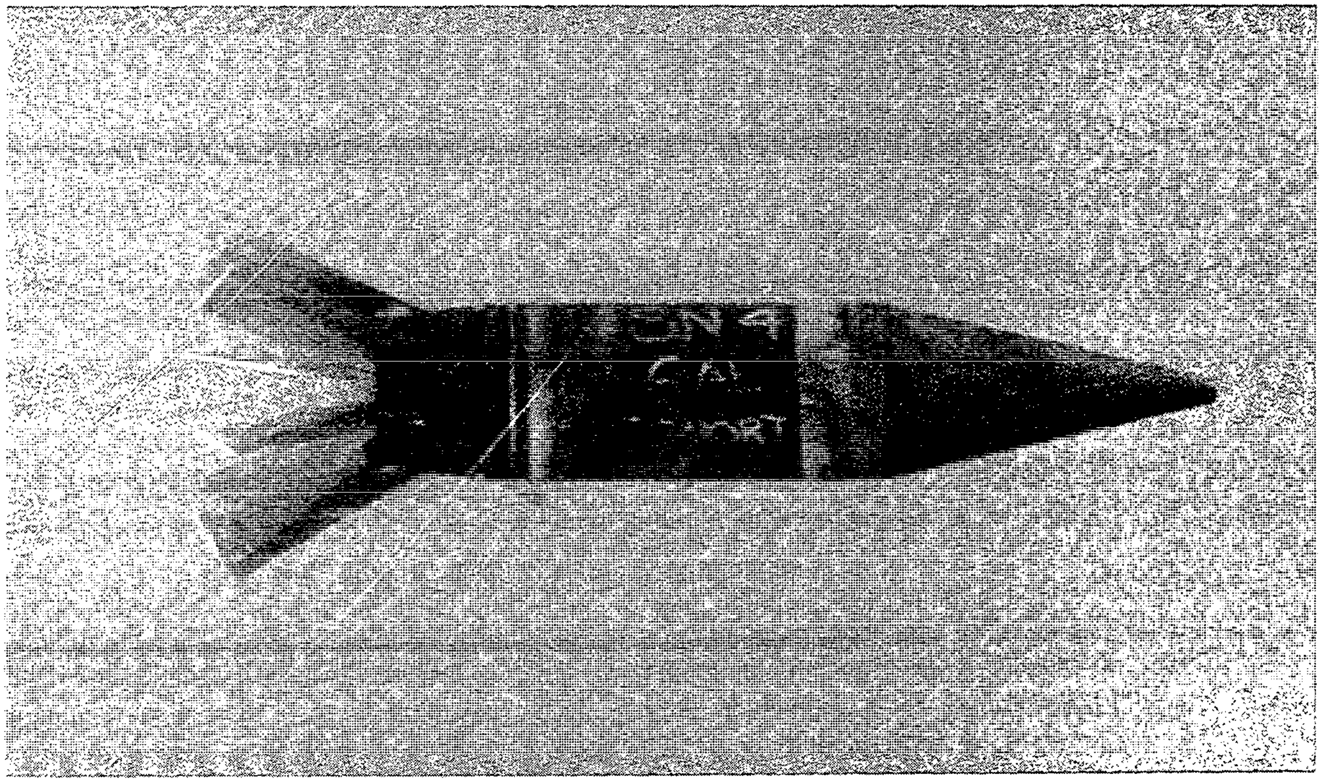


Figure 7. Round No. 33168, 2.74-m smear camera (short, thin Al fins).

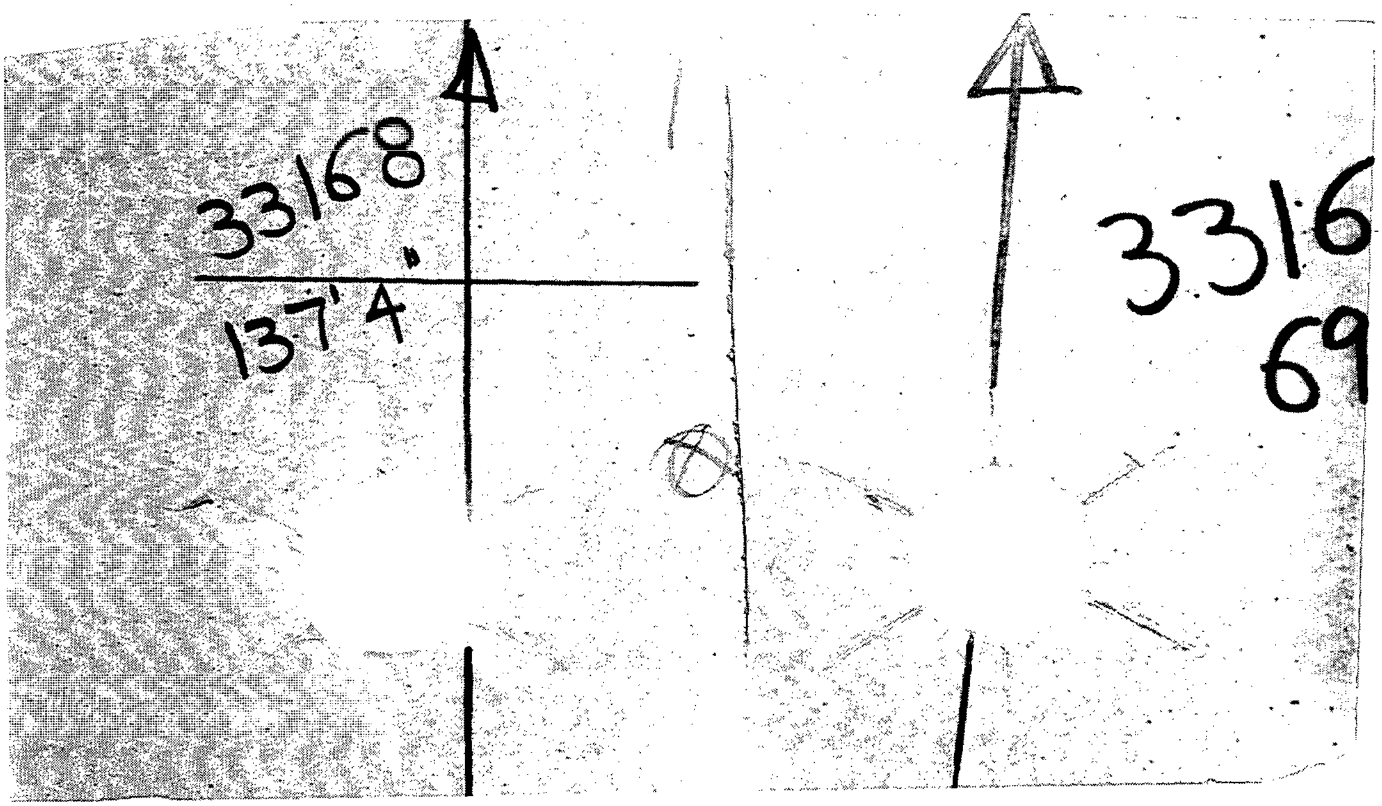


Figure 8. Round No. 33168, yaw cards from 137 ft 4 in (left) and 690 ft (right).

Figure 9. Round No. 33171, 32.31-m smear camera (short, thick Al fins with tabs).

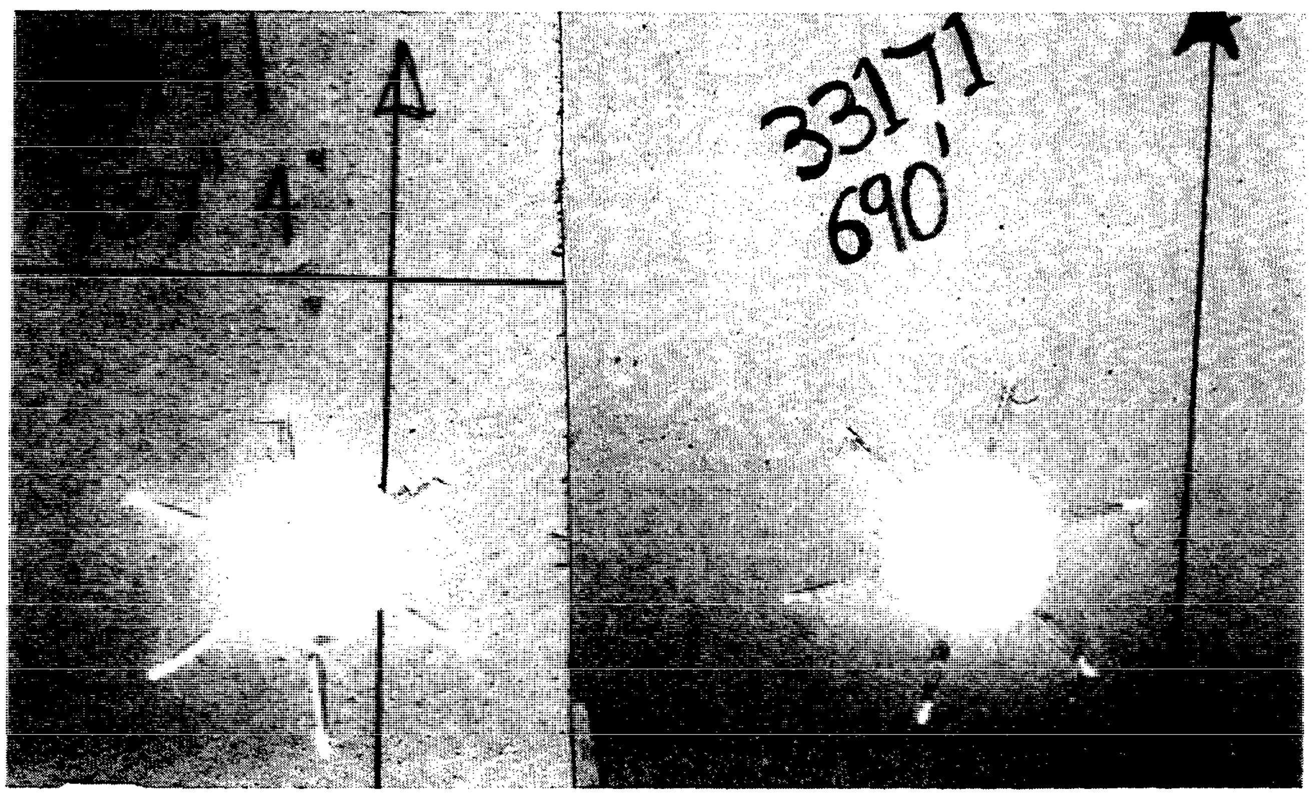


Figure 10. Round No. 33171, yaw cards from 137 ft 4 in (left) and 690 ft (right).

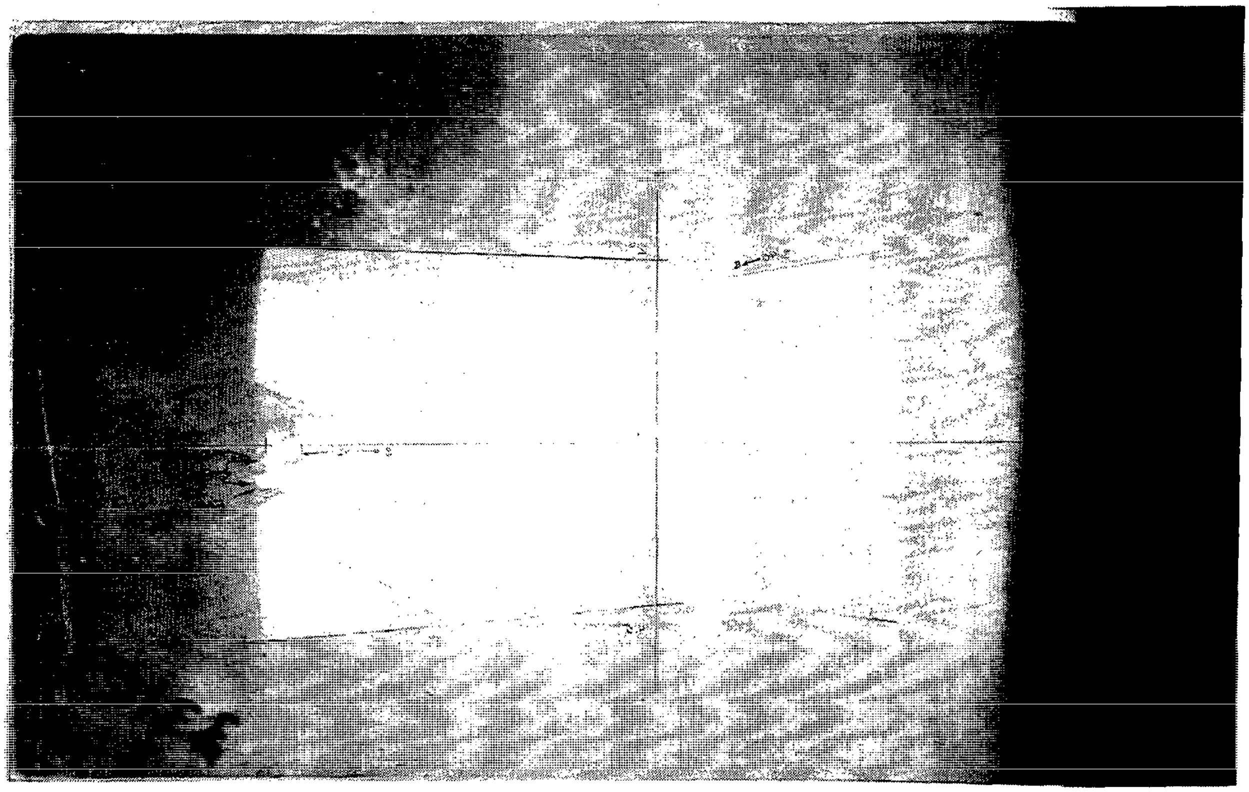


Figure 11. Round No. 33169, 0.24-m x-ray (X-Rod Ti fins with control tube).

Even though the Young's modulus of titanium exceeds that of aluminum by a factor of approximately 1.7, the X-Rod fin was tapered from 4.85 mm at the root to 0.59 mm at the tip with nearly sharp leading and trailing edges (Allegheny Ballistics Laboratory 1993). This geometry resulted in a fin that was much lower in stiffness than even the thin aluminum XM815 fin. Due to the reduced fin stiffness, these loads were able to produce large deflections in the titanium fins that were not experienced by the aluminum fins.

9. CONCLUSIONS

Both the gun tube and projectile experience lateral and angular motions during the in-bore cycle (Bornstein et al. 1989). Following shot exit, the tube and bullet are no longer mechanically constrained, allowing relative motion between the two. It is conjectured that this relative motion is sufficient to produce a misalignment between the fin surfaces and gun muzzle while the projectile is still within the reverse flow region. This misalignment is adequate to create asymmetric loading on the fins. Once an initial fin deflection is produced, the off-axis fin area presented to the flow is increased, thereby increasing the deflection. This synergistic effect occurs until the projectile exits the high pressure area of the reverse flow.

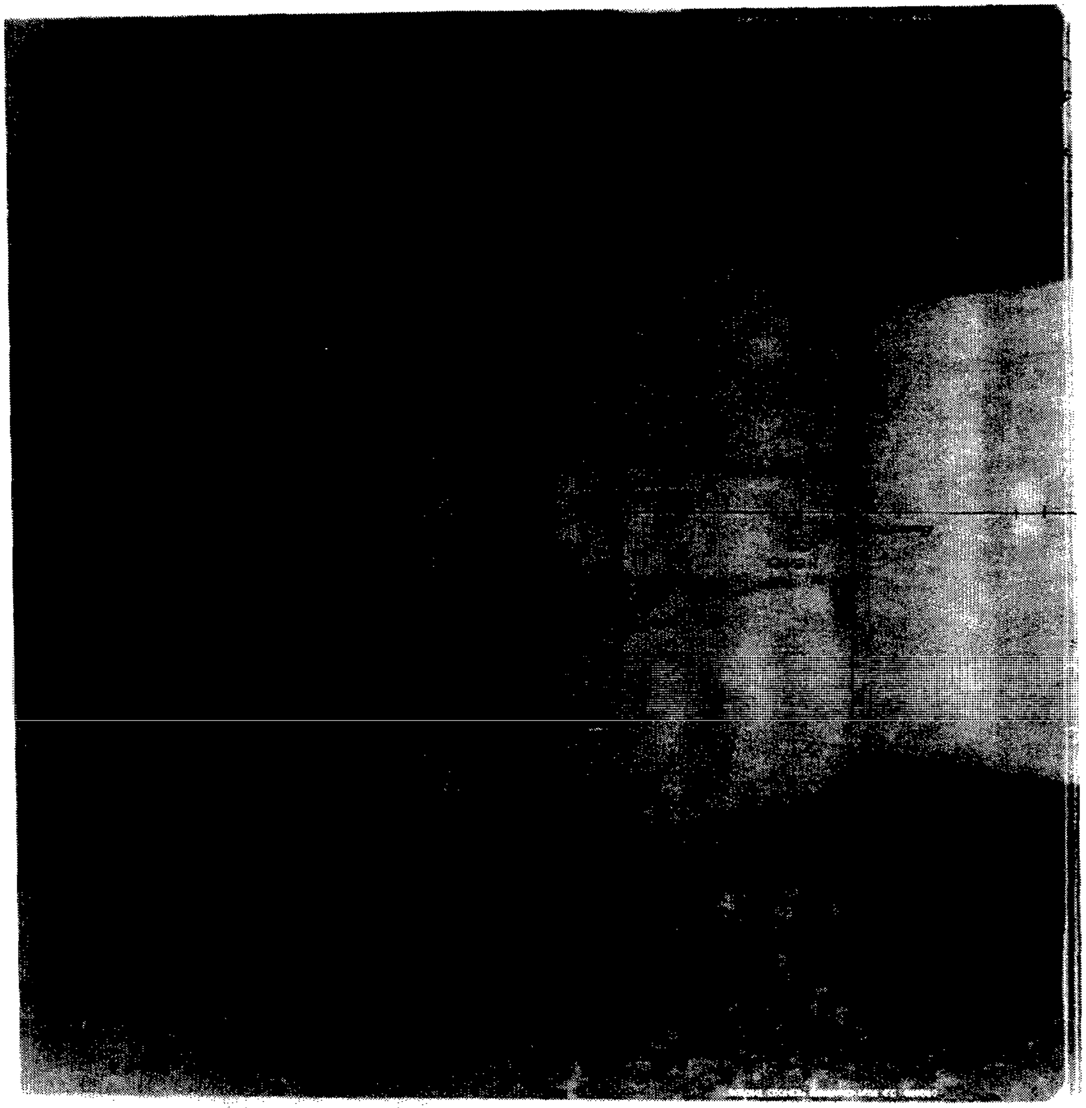


Figure 12. Round No. 33169, 1.05-m x-ray (X-Rod Ti fins with control tube).

The forward flip fin design appears to contain merit for certain tank projectile applications. However, these should be limited to smoothbore guns with fairly short, stiff fins. Distinctions among the fin designs (aluminum vs. titanium) were responsible for the varied responses observed within the muzzle flow field. Factors such as fin geometry (especially thickness), fin mass, fin inertial, and even differences in friction at the pivot point all contribute to deployment behavior. A kinematic analysis of the data could be applied to extract the resultant fin loads. These loads could then be used as a check for computational flow models attempting to simulate the muzzle flow. Such an analysis would provide a useful tool for future design iterations.

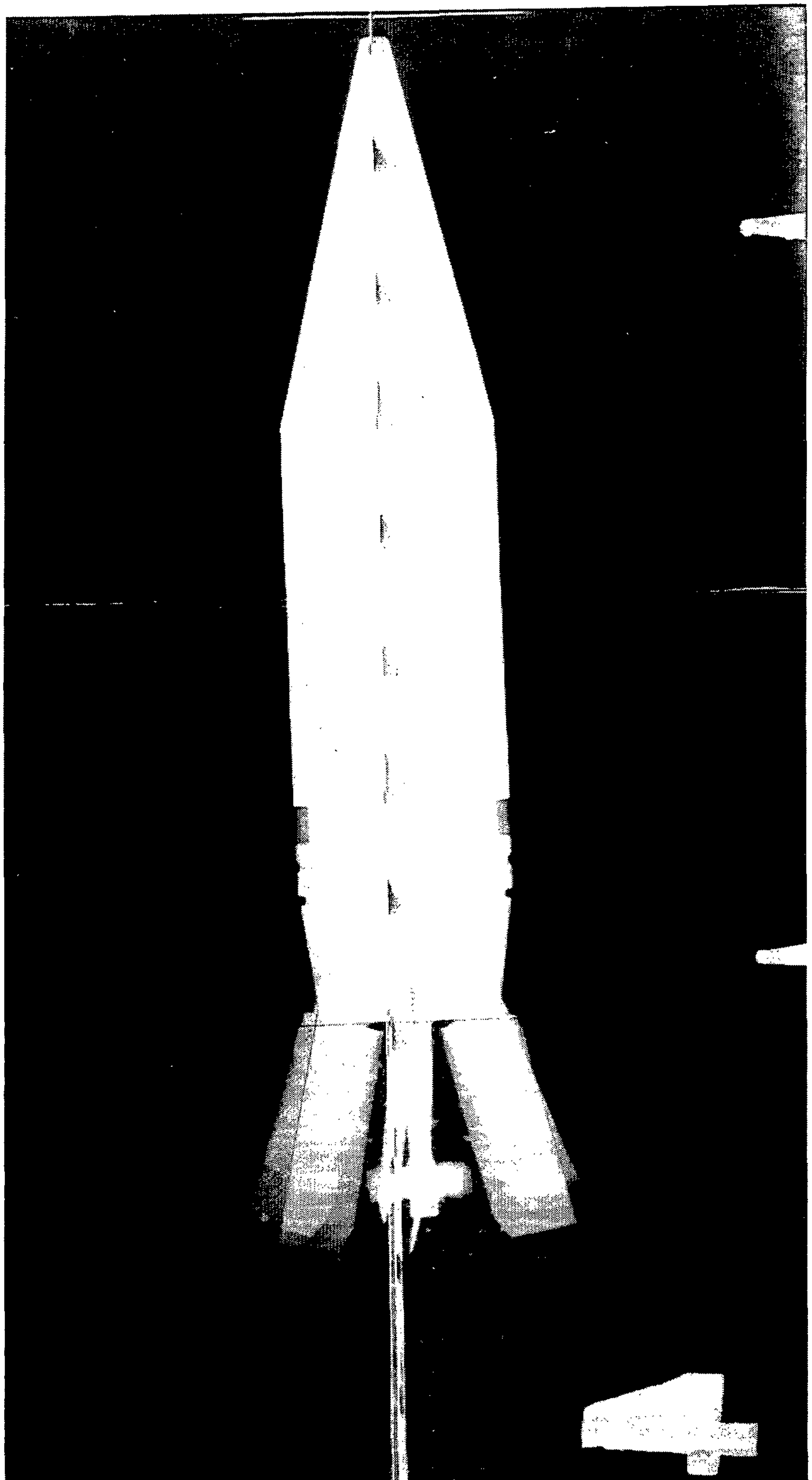


Figure 13. Round No. 33169, 4.33-m x-ray (X-Rod Ti fins with control tube).

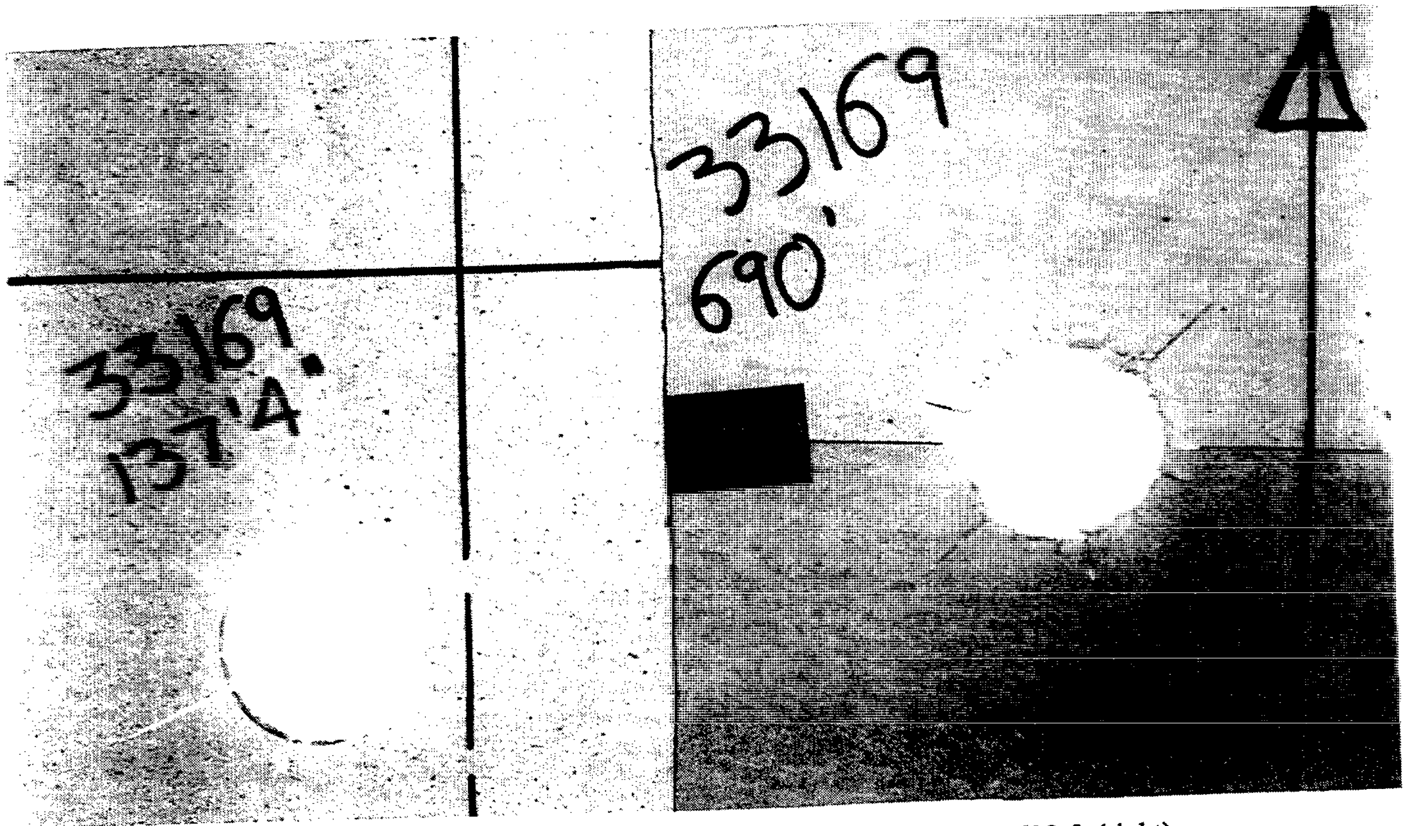


Figure 14. Round No. 33169, yaw cards from 137 ft 4 in (left) and 690 ft (right).

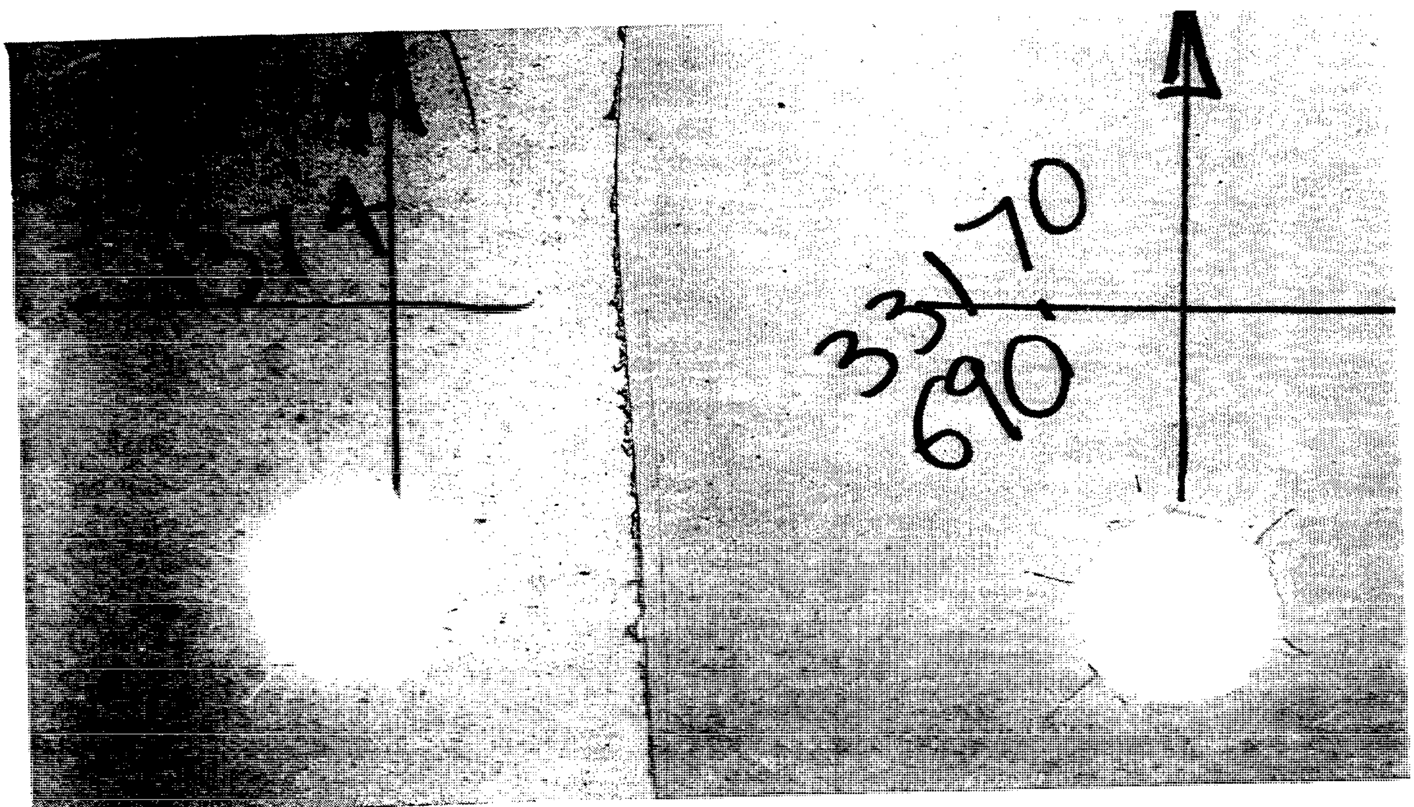


Figure 15. Round No. 33170, yaw cards from 137 ft 4 in (left) and 690 ft (right).

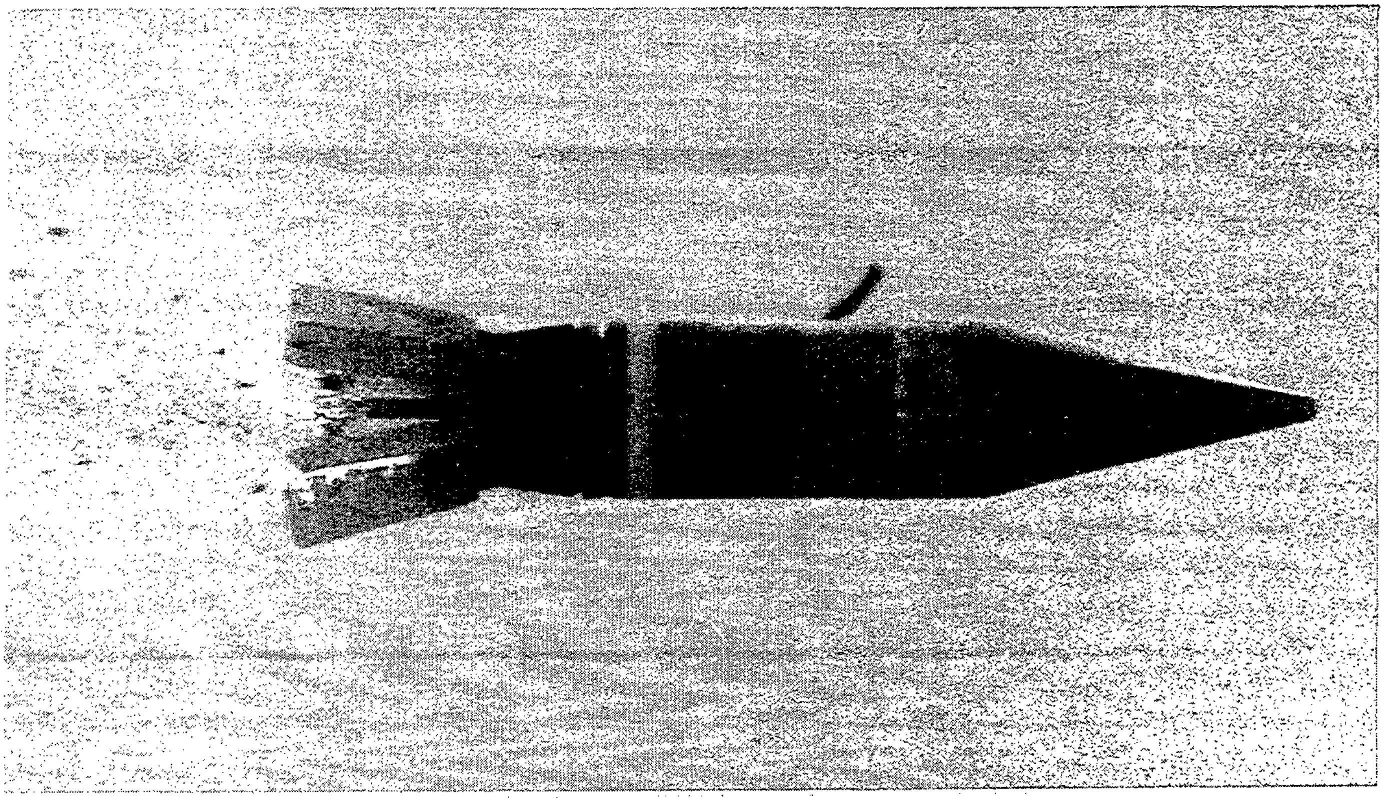


Figure 16. Round No. 33170, 2.74-m smear camera (X-Rod Ti fins with control tube).

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APPENDIX A:

XM815/X-ROD DATA OBSERVATIONS

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10/19/94 PM
Projectile SN 001 (Round No. 33165)

Configuration: Standard XM815 with thin Al fins, epoxy coated
Ctdg. Temp.: 70.0 F
Windspeed: 0
Relative Humidity: 81%
Ambient T: 65.9° F
Barometric Pressure: 30.00 in
Muzzle Velocity: 842 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 37.7 ksi, 40.0 ksi (Predicted: 38.4 ksi)

X-rays: All fins intact. Slight deflection of several fins noted at x-ray station 2. Inside fin corner (where trailing edge meets fin tip) is damaged on one fin; others appear undamaged. Fins appear close to full deployment by last x-ray.
Smears: All fins intact; epoxy coating flaked off near fin tips; five fins appear fully deployed.
Yaw cards: Five fins appear fully deployed at first card (137 ft 4 in); last fin partially deployed. Last card (690 ft) also indicates five fins fully deployed. Projectile has rotated approximately 180° between cards, as indicated by partially deployed fin.

10/20/94 AM
Projectile SN 002 (Round No. 33166)

Configuration: Standard XM815 with thin Al fins, epoxy coated
Ctdg. Temp.: 70.0° F
Windspeed: 0
Relative Humidity: 87%
Ambient T: 63.0° F
Barometric Pressure: 30.01 in
Muzzle Velocity: 847 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 39.8 ksi, 40.0 ksi (Predicted: 38.4 ksi)

X-rays: All fins intact. Several fins deflected through first three x-ray stations. One fin severely deflected. Deflections begin at station 1, increase in severity by station 2, and return to near straight condition by station 3. Station 4 reveals inside corner of one fin slightly bent, similar to damage seen in previous round. At last x-ray station, fins in varying deployment positions, one appears fully open.
Smears: All fins intact; luminous glow emanating from base of projectile; appears as though at least two fins, possibly up to four fins, not fully deployed. Epoxy coating washed from fin tips and trailing edges.
Yaw Cards: Only two fins appear fully deployed at first card (137 ft 4 in); projectile missed second card.

10/20/94 AM
Projectile SN 003 (Round No. 33167)

Configuration: Hybrid (three) X-Rod fins, Ti with ceramic coating, three XM815 thin Al fins, epoxy coated and cut to X-Rod length
Ctdg. Temp.: 70.0° F
Windspeed: 0
Relative Humidity: 87%
Ambient T: 65.0° F
Barometric Pressure: 30.01 in
Muzzle Velocity: 845.4 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 39.5 ksi, 39.9 ksi (Predicted: 38.4 ksi)

X-rays: No x-ray data due to early trigger.
Smears: All fins intact; first smear (9 ft) indicates that the XM815 fins are at or near full deployment, while X-Rod fins have rotated only slightly.
Yaw Cards: Three out of six (alternating) fins appeared to be fully deployed at both yaw cards, leaving a signature consistent with the XM815 fins. Two of the X-Rod fins were slightly opened while the third was completely closed, leaving no signature.

Note: After assembly, this round would not fit into the chamber gage. The ogive was then determined to be slightly oversized and was filed down to allow the round to properly gage.

10/20/95 PM
Projectile SN 004 (Round No. 33168):

Configuration: XM815 with thin Al fins, epoxy coated and cut to X-Rod length
Ctdg. Temp.: 70.0° F
Windspeed: 0
Relative Humidity: 87.5%
Ambient T: 64.7° F
Barometric Pressure: 29.98 in
Muzzle Velocity: 841.7 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 39.5 ksi, 39.6 ksi (Predicted: 38.4 ksi)

X-rays: All fins intact. No fin deflection appears at any x-ray position. Fins appear close to fully open by station 4.
Smears: All fins intact; most if not all fins appear to have reached full deployment. Epoxy coating was washed from fin tips and trailing edges.
Yaw Cards: Both yaw cards indicate that five of the six fins were fully deployed, while the last fin appears near full deployment.

Note: The next round to be fired would be the last for the day. Therefore, it was decided to fire an X-Rod configuration to provide direct comparison between fin types.

10/20/94 PM
Projectile SN 006 (Round No. 33169):

Configuration: X-Rod Ti fins, ceramic coated, with control tube simulator
Ctdg. Temp.: 70.0° F
Windspeed: 0
Relative Humidity: 87.5%
Ambient T: 65.0° F
Barometric Pressure: 29.98 in
Muzzle Velocity: 839.3 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 38.9 ksi, 38.7 ksi (Predicted: 38.4 ksi)

X-rays: Fin tips deflecting quite severely through first three x-ray stations. Control tube is possibly deflecting as well. Shower of particles, appear to be fin coating, surrounding rear of projectile and fins. Fins still deflected in station 4; some particles still around fins and trailing behind projectile. By station 4, fins are in varying positions, none more than approximately 33°.
Smears: All fins plus control tube intact. Luminous glow (burning) on fins where they rest in cradle and on cradle itself. This burning is not visible beyond second smear (22 ft 4 in). Also, a shower of flakes is evident around and behind the fins in the first smear (9 ft). The smears indicate that no fin achieved rotation of more than about 40°.
Yaw Cards: Both yaw cards indicate that none of the fins reached a position anywhere near full deployment. Each fin achieved some limited degree of deployment, each slightly different. Three of the fins appear to have closed slightly between the first and second yaw cards, but remain at least partially deployed. The remaining three fins appear to be stuck in the same position.

Note: A fin retaining ring was used on projectiles SN 006 and SN 007. The OD of this ring was larger than the ID of the case mouth through which it must pass. Upon assembly of SN 006, this retaining ring broke; therefore, masking tape was wrapped around the fins to hold them in place.

10/24/94 AM
Projectile SN 007 (Round No. 33170):

Configuration: X-Rod Ti fins, ceramic coated, with control tube simulator
Ctdg. Temp.: 70.0° F
Windspeed: 0
Relative Humidity: 80%
Ambient T: 59.7° F
Barometric Pressure: 30.12 in
Muzzle Velocity: 840.6 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 38.7 ksi, 40.3 ksi (Predicted: 38.4 ksi)

X-rays: Same shower of particles as previous shot. Severe fin deflections visible in station 2. Station 4 shows some particles, slight deflections, and one quarter of the retaining ring flying alongside the projectile. In addition, no fins are opened beyond about 20°.
Smears: All fins plus control tube intact. Same luminous glow from fin trailing edges and cradle as seen with SN 006. In addition, a similar shower of particles trailing behind projectile. Segment of the retaining ring was visible in the first two smears. No fin appears to have opened more than about 30°.
Yaw Cards: Both cards indicate that none of the fins reached a position anywhere near full deployment; however, they all opened slightly. It appears that all but one fin has rotated back toward the stowed position between yaw cards, with the last fin remaining constant.

Note: The retaining ring of SN 007 was carefully compressed to fit into the case mouth during the loading process.

10/24/94 PM
Projectile SN 005 (Round No. 33171):

Configuration: XM815 with thick Al fins, Al wedges on each fin tip, no coating.
Ctdg. Temp.: 70.0° F
Windspeed: 0
Relative Humidity: 75%
Ambient T: 69.3° F
Barometric Pressure: 30.65 in
Muzzle Velocity: 842.9 m/s (Predicted: 841 m/s)
Chamber Pressure (two) M11 crusher gages: 38.5 ksi, 39.4 ksi (Predicted: 38.4 ksi)

X-rays: All fins intact, however, all tabs discarding before first x-ray, indicating that the tabs came off immediately following muzzle exit. No fin deflection visible at any position. Station 4 reveals several tabs still visible on film, all fins straight, and open to about 30°.
Smears: All fins intact, all wedges torn from fin tips, discarding in a radial pattern. The wedges are visible in the first smear (9 ft) slightly ahead of fin tips in the axial direction. At every smear location, it appears that all fins have fully deployed.
Yaw Cards: First yaw card indicates all fins are fully deployed. Second card indicates all fins remained fully deployed; projectile has spun close to 135°.

APPENDIX B:

FIN OPENING ANGLES (X-RAY DATA)

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Table B-1. Fin Opening Angles*

Instrument	Distance From Muzzle (in)	Time From Muzzle Exit (μs)	Fin Angle Top Horizontal (°)	Fin Angle Bottom Horizontal (°)	Fin Angle Top Vertical (°)	Fin Angle Bottom Vertical (°)
Projectile SN 001, Round No. 33165 10/19/94, Configuration: Standard XM815						
X-Ray No. 1	9.32	491.6	1.5	0	1.0	3.0
X-Ray No. 2	41.40	1385.3	11.0	8.0	9.0	10.0
X-Ray No. 3	70.45	2278.3	21.0	NA	16.5	11.0
X-Ray No. 4	170.41	5298.0	33.0	34.0	35.0	27.0
Projectile SN 002, Round No. 33166 10/20/94, Configuration: Standard XM815						
X-Ray No. 1	9.32	551.6	2.0	2.5	4.0	4.0
X-Ray No. 2	41.40	1356.0	8.5	11.0	11.0	10.0
X-Ray No. 3	70.45	2226.0	11.5	NA	15.0	15.0
X-Ray No. 4	170.41	5298.1	11.0	34.5	25.5	31.0
Projectile SN 003, Round No. 33167 10/20/94, Configuration: Hybrid (3) X-Rod fins (3) XM815 fins cut to X-Rod length						
X-Ray No. 1	9.32	X-Ray data lost due to early trigger				
X-Ray No. 2	41.40					
X-Ray No. 3	70.45					
X-Ray No. 4	170.41					
Projectile SN 004, Round No. 33168 10/20/94, Configuration: XM815 fins cut to X-Rod length						
X-Ray No. 1	9.32	551.6	3.0	2.5	3.0	3.5
X-Ray No. 2	41.40	1356.0	10.0	10.0	11.5	11.0
X-Ray No. 3	70.45	2167.8	18.0	NA	15.5	15.5
X-Ray No. 4	170.41	5298.1	33.5	32.0	30.0	35.0
Projectile SN 006, Round No. 33169 10/20/94, Configuration: X-Rod with Ti fins and control tube						
X-Ray No. 1	9.32	551.5	3.5	4.5	4.5	2.0
X-Ray No. 2	41.40	1356.0	13.0	11.0	12.5	9.5
X-Ray No. 3	70.45	2167.8	13.0	NA	16.0	17.0
X-Ray No. 4	170.41	5298.1	11.0	31.5	21.5	22.5

* Angle measurements refer to the fin opening angle, with respect to the projectile centerline, measured in the respective x-ray film plane.

Table B-1. Fin Opening Angles (continued)*

Instrument	Distance From Muzzle (in)	Time From Muzzle Exit (µs)	Fin Angle Top Horizontal (°)	Fin Angle Bottom Horizontal (°)	Fin Angle Top Vertical (°)	Fin Angle Bottom Vertical (°)
Projectile SN 007, Round No. 33170 10/24/94, Configuration: X-Rod with Ti fins and control tube						
X-Ray No. 1	9.32	551.5	NA	NA	NA	NA
X-Ray No. 2	41.40	1356.1	9.0	9.0	7.0	8.0
X-Ray No. 3	70.45	2167.7	12.5	14.0	12.5	14.0
X-Ray No. 4	170.41	5298.8	13.0	13.5	17.0	20.5
Projectile SN 005, Round No. 33171 10/24/94, Configuration: XM815 with Al fins cut to X-Rod length and wedges on fin tips						
X-Ray No. 1	9.32	551.6	3.0	NA	4.5	4.0
X-Ray No. 2	41.40	1355.9	12.0	15.5	14.0	13.0
X-Ray No. 3	70.45	2167.7	NA	22.0	23.0	20.5
X-Ray No. 4	170.41	5298.8	35.0	33.0	30.0	28.5

* Angle measurements refer to the fin opening angle, with respect to the projectile centerline, measured in the respective x-ray film plane.

APPENDIX C:

VELOCITY vs. TIME PLOTS

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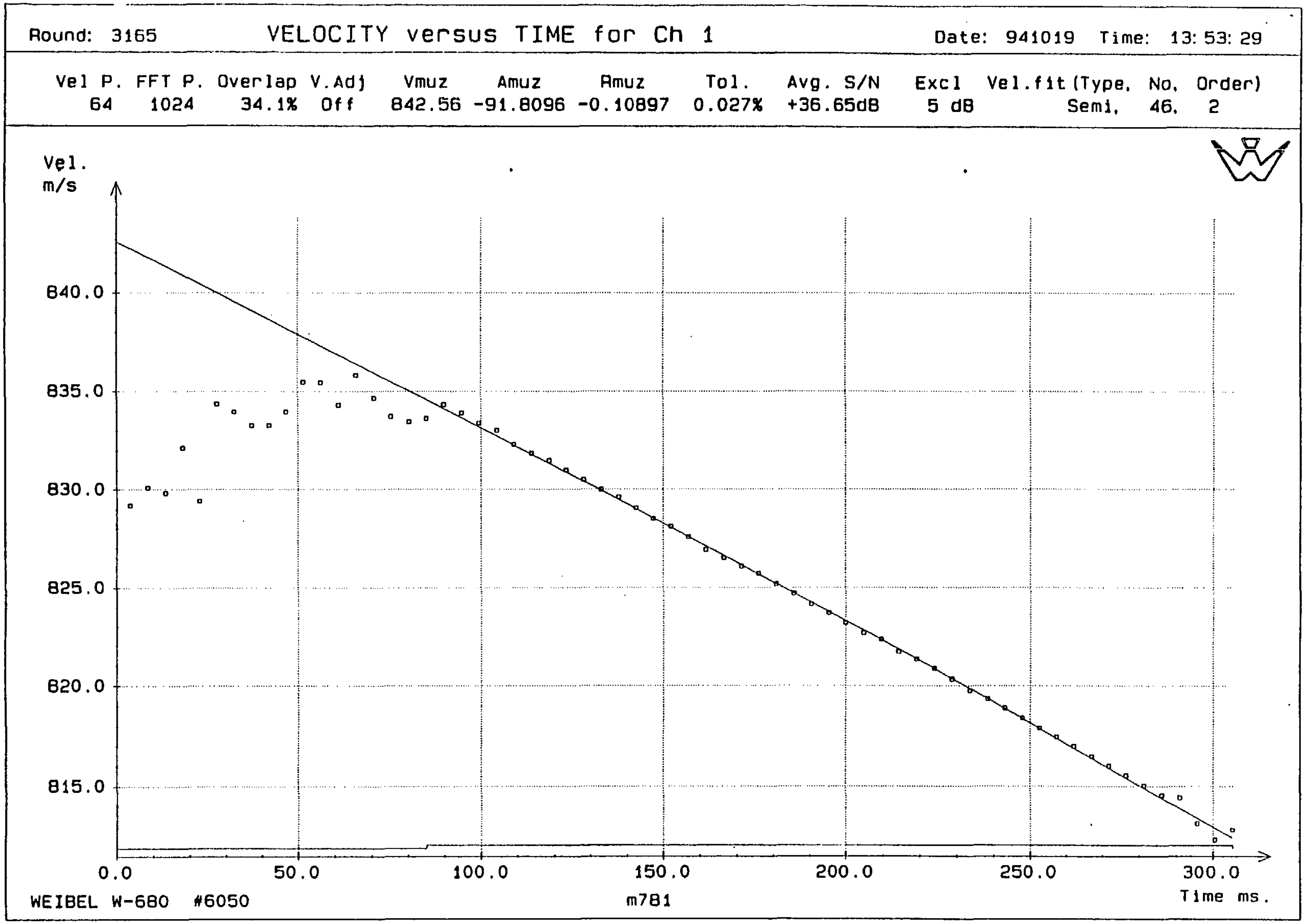

Figure C-1. Velocity vs. time plot for round 33165.

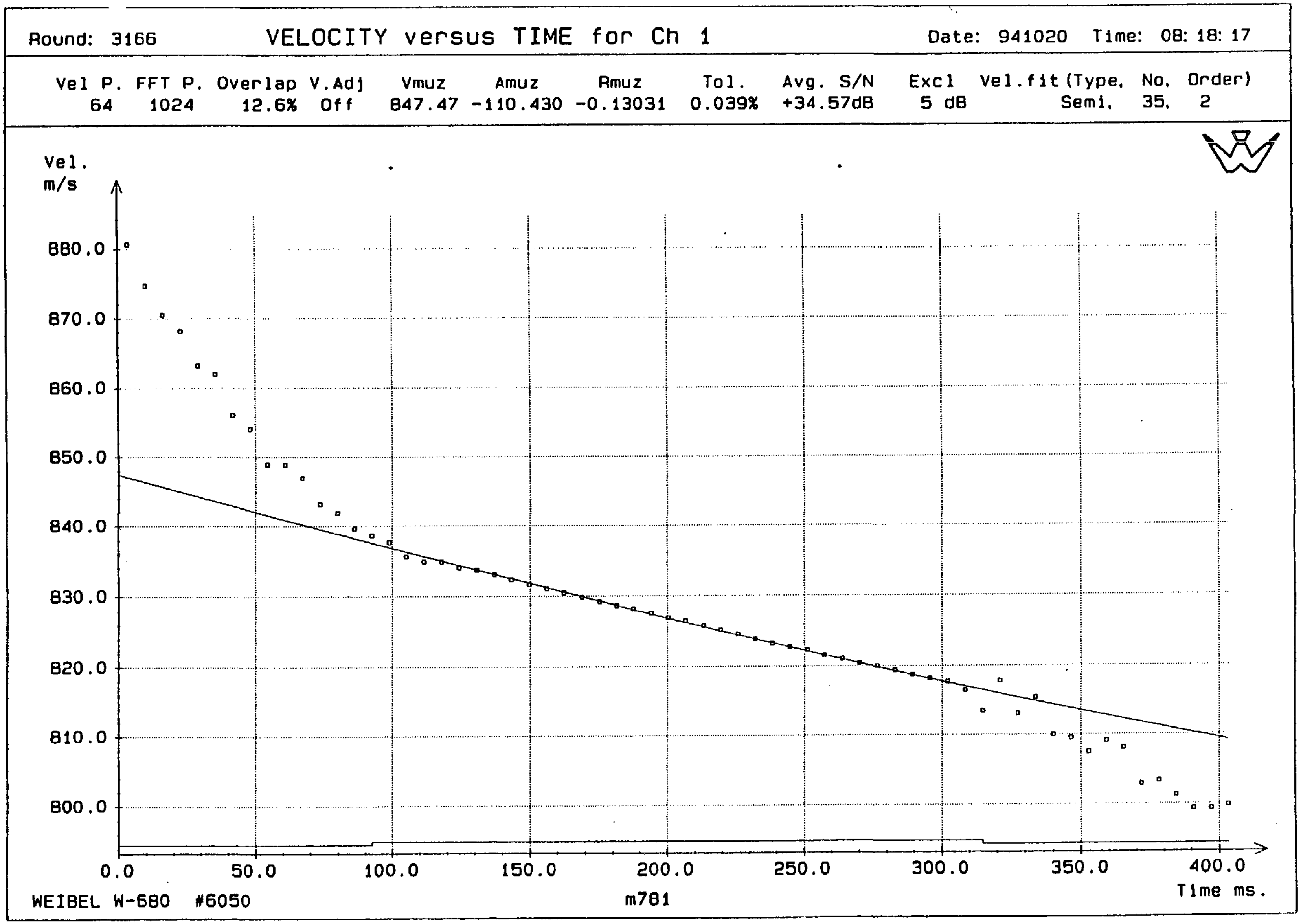

Figure C-2. Velocity vs. time plot for round 33166.

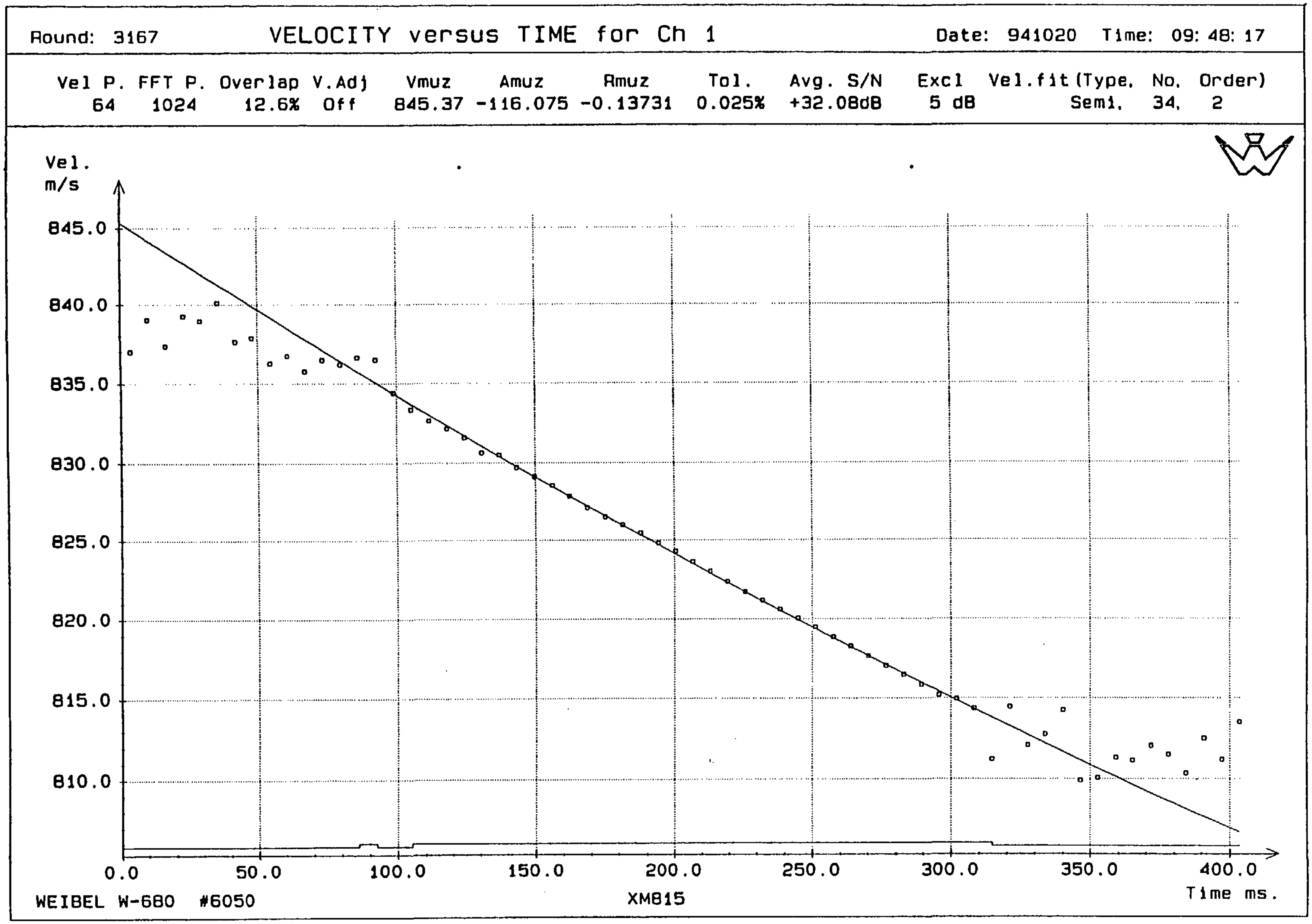

Figure C-3. Velocity vs. time plot for round 33167.

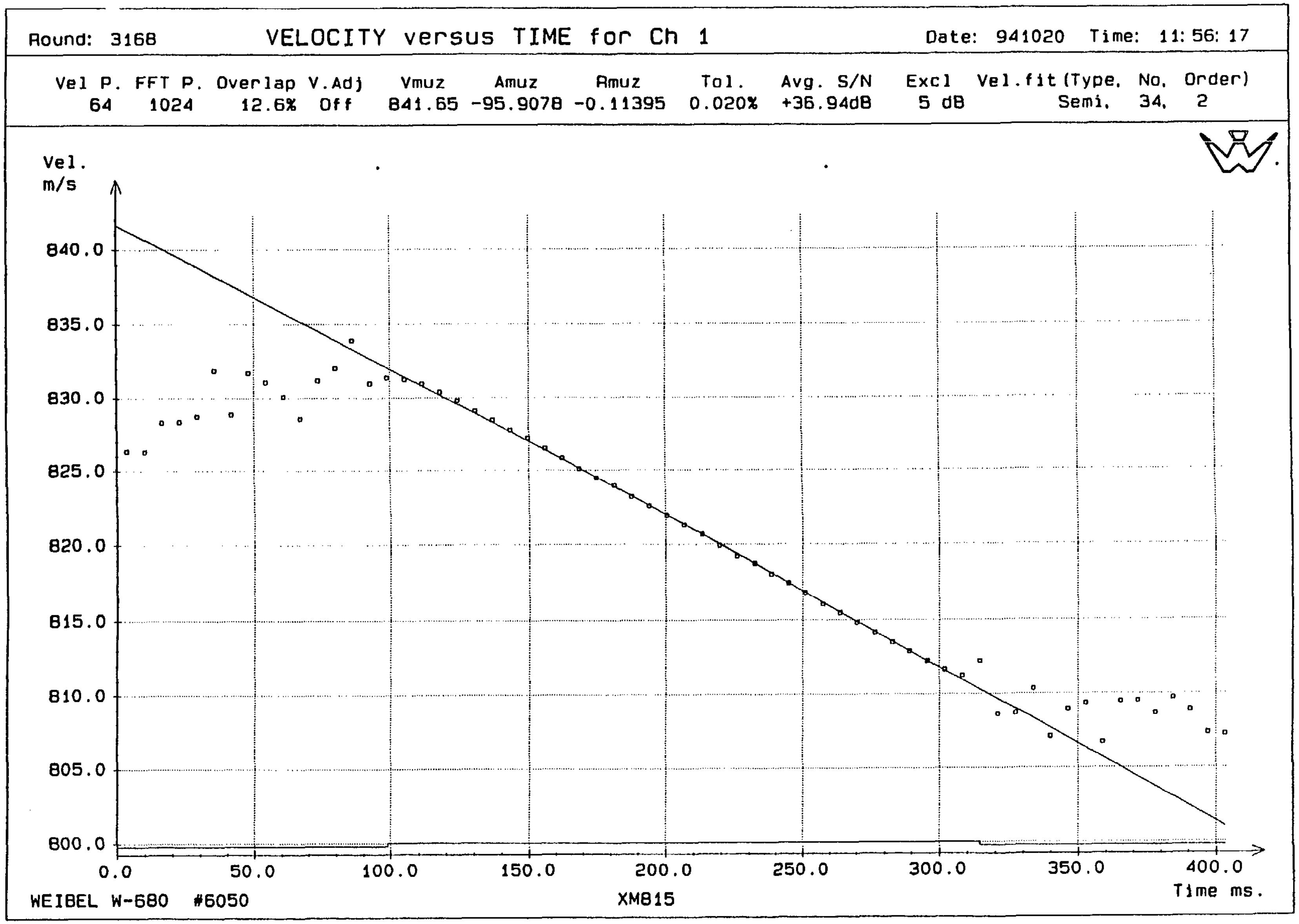

Figure C-4. Velocity vs. time plot for round 33168.

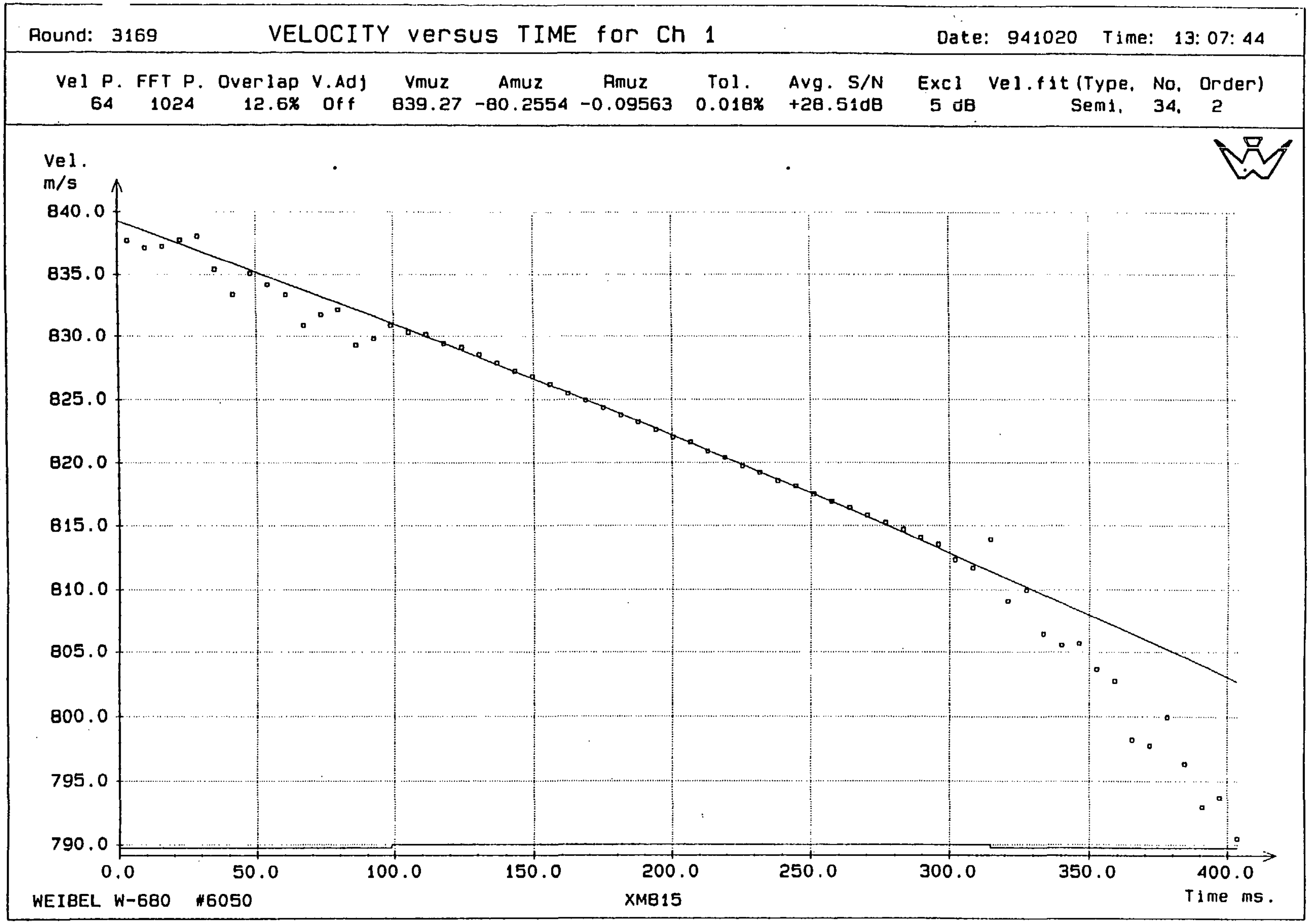

Figure C-5. Velocity vs. time plot for round 33169.

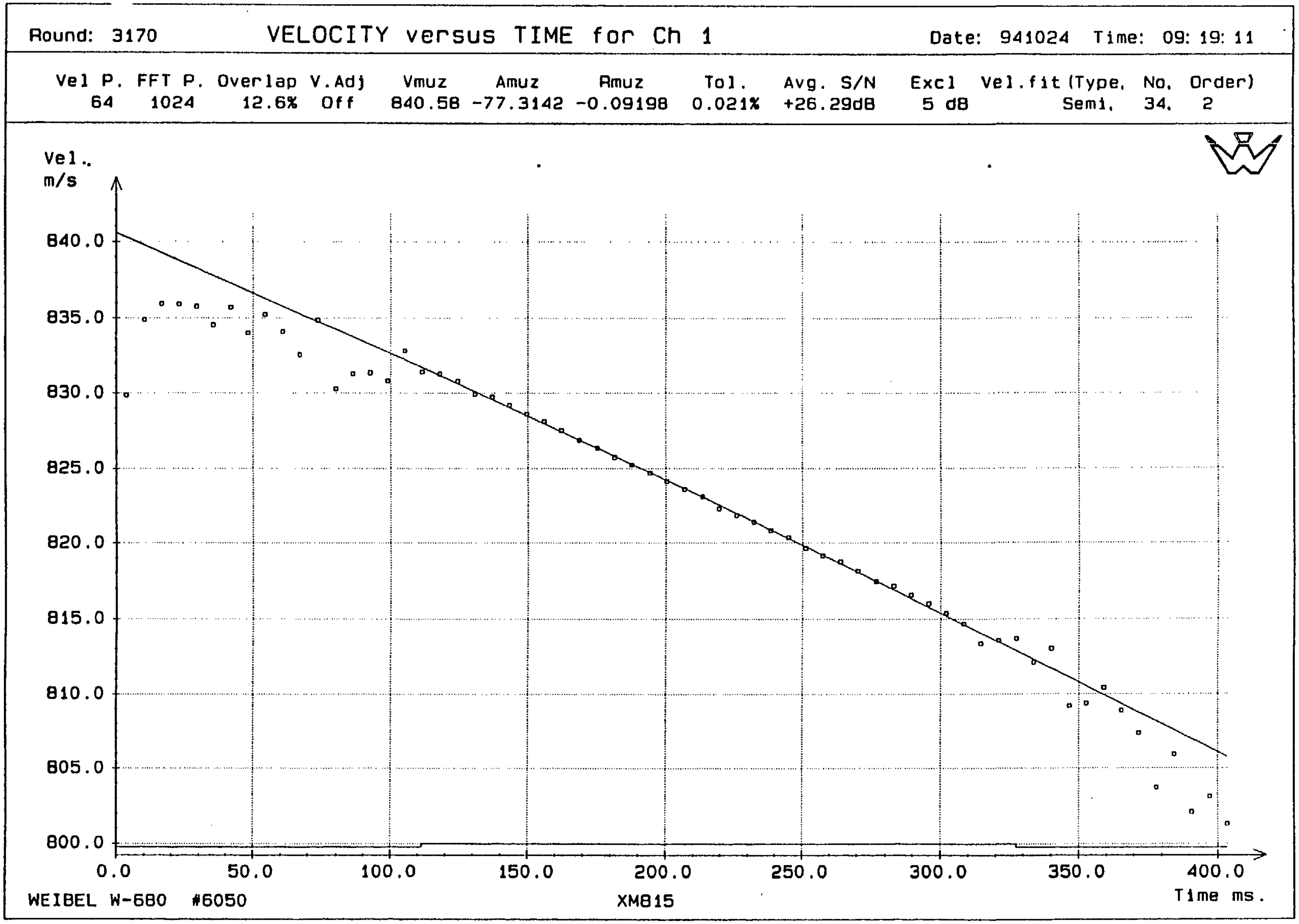

Figure C-6. <u>Velocity vs. time plot for round 33170</u>.

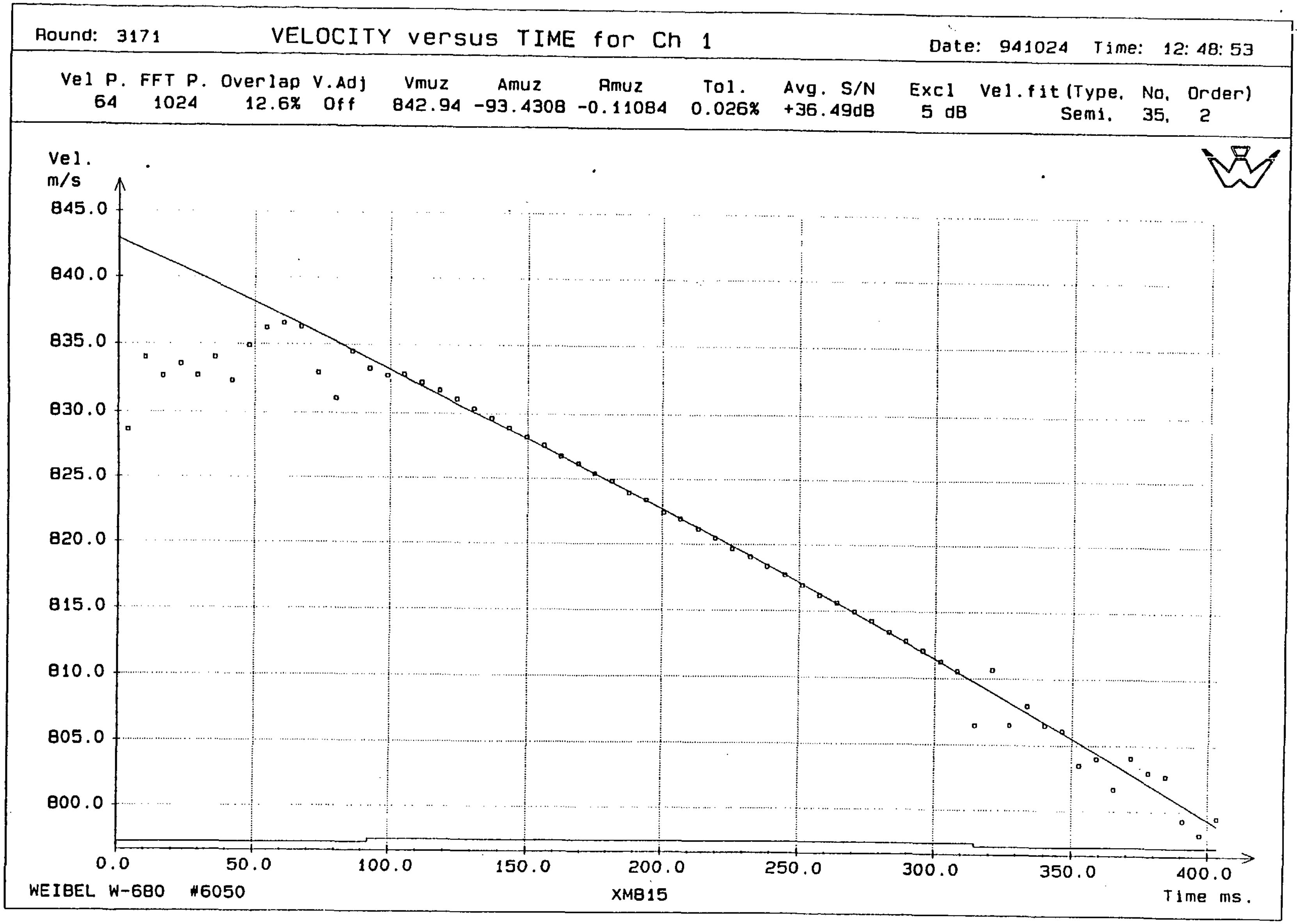

Figure C-7. Velocity vs. time plot for round 33171.

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